Lessons learned from the island LCCs: toward best practices to address unique LCD challenges

Authors (alphabetical):

- Laura Brewington[a]
- Jeff Burgett[b]
- Brent Murry[c]
- Aaron Poe[d]

[a] East-West Center, Honolulu, HI 96844 USA
[b] US Fish and Wildlife Service, Pacific Islands Climate Change Cooperative, Honolulu, HI 96813 USA
[c] US Fish and Wildlife Service, Caribbean Landscape Conservation Cooperative, San Juan, PR 00926, USA
[d] US Fish and Wildlife Service, Aleutian and Bering Sea Islands Landscape Conservation Cooperative, Anchorage, AK 99503 USA

Keywords: Climate change, Endemism, Fragmentation, Islands, Isolation, Landscape Conservation Design, Social Capacity, Terrestrial-Marine Systems

I. Abstract

The US Department of the Interior's Landscape Conservation Cooperatives (LCCs) are regional applied conservation partnerships, which together form an international network of scientific and management expertise to sustain the natural and cultural diversity of landscapes and seascapes. Landscape Conservation Design (LCD) is a framework that the LCCs use to identify shared priority resources and develop strategies to shape the future conservation landscape, but as it is currently conceived it's based on assumptions derived from regions with high institutional capacity that are homogenous and mostly continental. Ecological and societal features of islands that are critical to effective conservation design differ markedly from continental settings. While the field of LCD manifests and matures, there is space and a need for developing a more robust framework that is inclusive of these unique and vulnerable settings. This analysis summarizes key island features that vary in degree by archipelago and underscore the challenges of applying LCD, including endemism, connectivity and scale, linkage of terrestrial and marine systems, exposure to climate change, and social/political capacity. Using the three island LCCs and their challenges and successes as examples, five strengths and opportunities are identified that advance the concept and practice of LCD in diverse and changing settings throughout the network.

II. Introduction

Islands are home to vulnerable iconic species and unique habitats that are the focus of global conservation efforts. Within the jurisdiction of the United States and affiliated islands and territories, the US Department of the Interior has established Landscape Conservation Cooperatives (LCCs) to foster collaborative conservation efforts at landscape scales, raising the question of how best to plan and conduct landscape-scale conservation in island settings. Three of the 22 LCCs are comprised entirely of islands, while several others contain islands of high conservation value (Figure 1). Isolated by definition, and often small, remote, and with complex social and ecological features, some island settings require a different process framework for developing conservation designs than their continental counterparts. Because many continental areas share some of these features with islands, however, an optimal LCD framework for the network should be applicable and useful beyond the island LCCs.

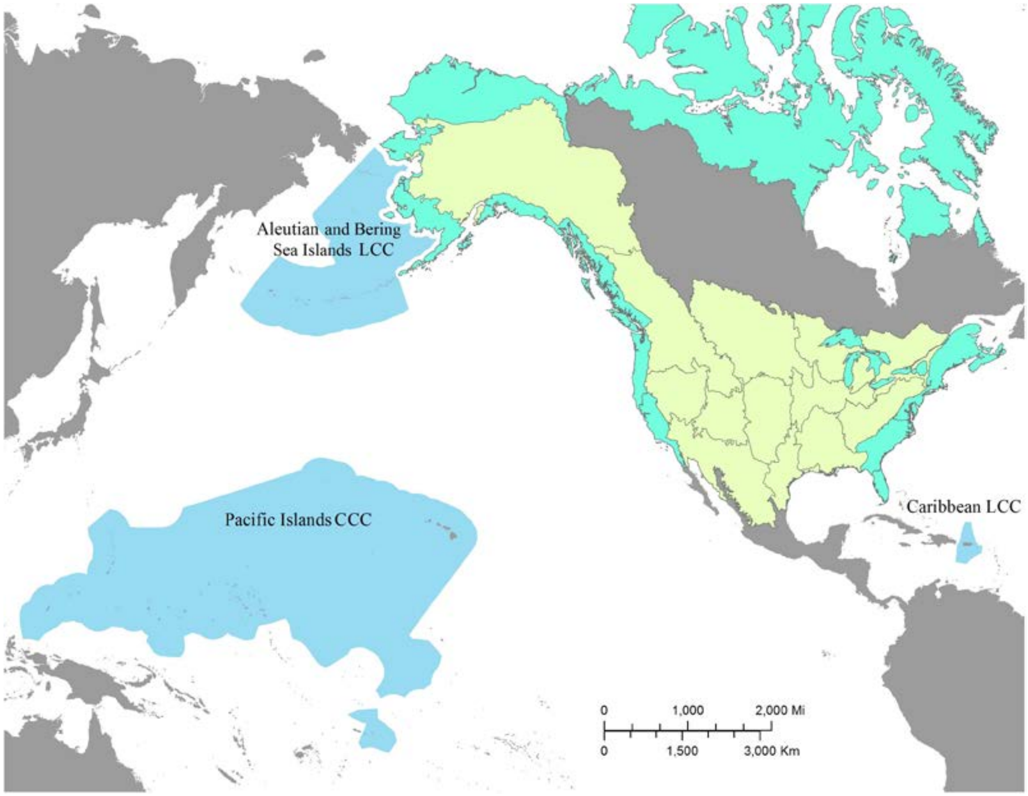

Figure 1. The 22 LCCs that make up the network. Three LCCs are comprised entirely of islands (blue), while several others contain islands (teal).

Within the LCC network, a Landscape Conservation Design (LCD) framework is being formalized as the planning and reporting tool for meeting the US Fish and Wildlife Service's (USFWS) Strategic Habitat Conservation goals (USFWS 2008). LCD is defined as both a process (to design) and a product (the design) "that achieves partners' missions, mandates, and goals while ensuring sustainability of ecosystem services for current and future generations" (Campellone et al. 2014). LCD is stakeholder-driven, science-based, technologically advanced, and spatially-explicit, identifying targets of interest, articulating measurable objectives, assessing current and projected landscape patterns and processes, and identifying desired future conditions and the implementation strategies needed to achieve them. The seven phases that make up this preliminary version of LCD set biological, ecological, and cultural goals for priority resources, and assemble climate, land cover, land use, hydrological and other relevant data to define and predict landscape patterns. Landscape-level management strategies are developed to achieve the stated goals, and assumptions about the system are reviewed for new threats to and information about the conservation priorities. A variety of adaptive management protocols can then be implemented that contain research, modeling, and monitoring elements (Nassauer and Opdam 2008; Ehler and Douvere 2009; Chapin III et al. 2010).

In this paper, we introduce the core concepts of this developing LCD framework for the LCC network, and then briefly review the literature on five key features of island settings: endemism, connectivity and scale, land and sea linkages, socio-political complexity, and exposure to climate change. These features can pose significant challenges to the application of LCD, not only in island geographies but in comparable continental settings, as well. However, we argue that they can also be viewed as "bridging" issues between islands and continents in the context of LCD. Our goal is to contribute to the broader conversation about landscape conservation by identifying ways in which characteristics that are specific, but not limited, to islands can inform LCD approaches that are different from the dominant models being applied in continental settings. We conclude with a discussion of how the strengths and opportunities drawn from island LCC experiences can broaden the diversity of approaches to LCD that could be employed throughout the LCC network, providing a flexible and powerful tool for the wide variety of settings in which the LCCs must succeed.

III. Landscape Conservation Design

The LCCs share a goal, stated in the National Fish, Wildlife and Plants Climate Adaptation Strategy (NFWPCAP 2012), to identify priority areas for landscape-scale, connected conservation efforts in the face of changing climate, human, and ecological conditions. This goal requires use of design processes that lead to sustainable or functional landscapes over the long term. This includes identification of appropriate areas for development and priority areas for conservation, within clearly defined geographies that are affected by broad-scale stressors. Essentially, LCD identifies what the priority targets are, where actions should be taken to achieve those targets, and for what purpose. A multi-faceted understanding of landscape processes and patterns underpin the setting of conservation targets, requiring input from diverse stakeholders and explicitly linking decision making with ecosystem function (Campellone et al. 2014). The seven phases of the preliminary LCD framework (Campellone et al 2014) form the foundation of the USFWS adaptive management strategy to design, coordinate, and deliver management actions at the landscape scale (USFWS 2008).

Phases 1 (Kick-off) and 2 (Pre-assessment) focus on convening stakeholders, identifying threats to the sustainable function of the landscape, and then setting priority conservation targets (or resources) and measurable objectives to address those threats. Geographic planning units are identified, and existing conservation efforts are analyzed to assist in priority setting using the best available ecological and social information. Goals (i.e. targets) are linked to the ability of current and future landscapes to support desired resource levels at appropriate spatial scales across an LCC's geography. In Phase 3 (Assessment) the LCC partners generate a baseline assessment of the landscape and define future scenarios based on identified driving forces of change. By assessing landscape conditions, a better understanding of the relationship between targets and threats is obtained, and empirical and conceptual models are developed to analyze the current state of priority resources[1]. LCC staff and partners coordinate and conduct vulnerability assessments specific to the priority resources, which consider current and expected future conditions of landscapes, and these two sets of analyses are used to evaluate the capability of the LCC to support its objectives.

In Phase 4 (Post-assessment), scenarios of desired future landscape conditions are developed, with model outputs of particular landscape components, diagrams, and interactions. The LCCs incorporate traditional environmental knowledge and stakeholder feedback into the design, and generate a refined list of data limitations and gaps to guide future research. Phase 5 (Pre-design) compares the priorities of the LCC with a range of future landscape conditions, as well as conservation deficits (the differences between the current and desired future landscape conditions) that must be met to achieve objectives. Partners come to agreement on the technical aspects of the design, as well as any revised goals for desirable/undesirable future landscape conditions. This paves the way for Phase 6 (Design), where spatially-explicit conservation strategies and a suite of management practices are introduced that reflect the ability of current and future landscapes to support the LCC's priority resources. The design output is a portfolio of priority areas and best practices to achieve the goals, and it should have broad generalizability or transferability within the LCC and its neighboring regions, where applicable.

---

[1] The set of biological, ecological, and cultural features and ecological processes that have been collaboratively identified by LCC Steering Committees and that are the focus of the LCC's planning, science, and measurable objectives (http://www.fws.gov/science/pdf/SIAS-FY2013.pdf).

In the final phase (Post-design), strategies are implemented by partners. For example, an adaptation strategy may consider the effects of climate and land use change on ecosystem services provision for the LCC's priority resources. Site-specific monitoring and evaluation criteria are used to assess the effectiveness of the LCD in achieving collaboratively-defined desired future landscape conditions.

IV. Key Island Features and Challenges for LCD

As intimated above, conservation design at the landscape scale is most easily conceived in settings that are relatively spatially large, contiguous, and homogenous, featuring multiple high-capacity partners and stakeholders with existing portfolios of priority targets or areas and associated implementation strategies. However, several key features of islands, which vary in degree by archipelago, pose challenges for applying LCD in those settings. These features include endemism, connectivity and scale, linkage of terrestrial and marine systems, social/political capacity, and exposure to climate change.

Endemism

Isolation is a defining and uniting feature of nearly all island systems, creating microcosms of flora and fauna unique to each. The formation of endemic biotas occurs both on islands that were once part of an initial continental land mass (island fragments), as well as oceanic or "Darwinian" islands formed as a result of volcanic activity or coral uplift (Gillespie and Roderick 2002). Endemic species on island fragments may be relic members of their former continental and now-diverged species, a feature also of continental areas that are "similar" to islands. An example is the "sky islands" of the desert Southwest, where surrounding inhospitable terrain has isolated species over evolutionary time. In contrast, endemics on Darwinian islands exhibit ongoing or relatively recent processes of evolution or adaptive radiation. Higher species richness is, in general, found on larger islands closer to continental land masses, while the decreasing size and increasing isolation of an island leads to lower diversity (MacArthur and Wilson 1967). All told, islands usually exhibit much higher levels of endemism than their continental cousins, but lower species richness (Whittaker and Fernandez-Palacios 2007; Kier et al. 2009).

Island endemics have suffered the majority of historical extinctions (Simberloff 2000a; Duncan et al. 2013) and many are currently under severe threat due to land use change, habitat loss, and the effects of invasive species (Myers et al. 2000; Blackburn et al. 2004; Clavero and García-Berthou 2005; Buckley and Jetz 2007). Island endemism poses a particular management challenge because these species have very limited geographic distributions and small population sizes (Gillespie 1999; Simberloff 2000b; Fordham and Brook 2010). Since these species are restricted to islands or even portions of islands, design options are confined to these islands rather than involving a larger regional landscape so that each island becomes a separate LCD problem for its endemic species. Multiple rare endemic species with small ranges mean that more must be known and modeled to set goals for a given area in LCD, and this also leads to a large number of targets for monitoring and management. Lack of data on rare species or endemics that inhabit hard-to-reach areas further complicate conservation planning at the regional or landscape level (Feeley and Silman 2011). High endemism is not limited to the terrestrial regions of islands, as many intertidal and coral reef systems host marine hotspots for diversity (Allen 2008).

Perhaps the greatest threats to island endemics are non-native invasive species, whose arrival to ecosystems outside of their normal range is mediated by human transport or habitat alteration (Vitousek et al. 1997; Sax and Gaines 2008). Their impacts can range from extinctions, alteration of ecosystem function, or even total ecosystem collapse, while the removal of introduced organisms may also have unpredictable or undesirable effects (Zavaleta et al. 2001; Courchamp et al. 2003; O'Dowd et al. 2003; Simberloff 2011). Conversely, where it is feasible, islands provide ideal opportunities for complete eradication of invasive species, and subsequent recovery of island endemics and other native species (Veitch and Clout 2002). Preventing invasions is the most cost-effective means of protecting endemic island species (Lodge et al. 2006), but interfering with the processes that facilitate invasions (e.g.

commerce) can be more challenging for LCD than addressing established invasives through spatial planning and management.

Connectivity and Scale

The fundamentally disconnected nature of islands makes each island itself the logical unit of conservation design for terrestrial species (Cook et al. 2006). Most islands host a unique suite of these species (both native and invasive), as well as unique histories of human settlement, cultural development, and governance, which are a product of island isolation. But with greater movement of people and goods around the globe, LCD for island settings needs to address connectivity in terms of threats and development of optimal actions. It is also important to consider that islands of an archipelago that share characteristics of genetic makeup, disturbance, or ecosystem function – potential priorities for LCD – may not be geographically near one another (Cook et al. 2006). Therefore, an adequate conservation design at the landscape scale for islands must account for diverse phenomena spread out over large geographic units that are not homogenous. A design process that incorporates inter-island exchanges and shared terrestrial/marine corridors may be appropriate for conservation targets with greater dispersal capabilities, while a focus on archipelago-wide or even island-to-continent connectivity may be needed for priority species, habitats, or ecosystems that encompass broad ranges.

In continental settings, biodiversity conservation at the landscape level often focuses on preserving, restoring, or creating habitat connectivity or wildlife corridors (Gilbert-Norton et al. 2010). On larger islands, restoring lost landscape connectivity can indeed be as crucial to species and ecosystem survival as in continental areas, but the scale tends to be much smaller (Cuaron et al. 2004). Habitat connections to accommodate range shifts from climate change on islands must be mostly altitudinal as opposed to lateral (Harter et al. 2015). Compared to continental settings, corridor planning is therefore simpler and involves much smaller distances, but must contend with rapidly decreasing habitat area at higher elevations (Harter et al. 2015).

Actively maintaining or restoring the original isolation of islands can be a key aspect of island LCD, because human transport among islands and from mainland environments creates the invasive species problems that plague island biotas. Both within and among islands, invasive species dispersal is facilitated by connectivity through human activities and natural disturbance. Global and local transportation networks are known pathways for species introductions to oceanic islands (Poirine and Moyrand 2001), particularly by air and sea cargo (Ruiz and Carlton 2003; Rodda and Savidge 2007; Russell et al. 2008; Kaluza et al. 2010). Ballast water transport, aquarium releases or escapes, and aquaculture are common mechanisms by which invasive species colonize new island and marine environments (Simberloff 2000b; Hulme 2009).

For marine and nearshore management, connectivity is a key component of conservation and ecosystem productivity (Almany et al. 2007; Gaines et al. 2010), and the size and spacing of protected areas are essential to species dispersal rate and success (Halpern and Warner 2003; Planes et al. 2009). Marine connectivity is difficult to measure or map, often requiring genetic tracers within a medium that is fluid and constantly changing (Planes et al. 2009). Establishment of individual Marine Protected Areas may reflect the needs of particular species or groups, but not the sustainability of the larger “marine-scape,” to relate it to the way that LCD has been applied in terrestrial settings across landscapes (Meyer et al. 2007). The creation of a network of connected Marine Protected Areas is one way to enhance large-scale conservation design to span the marine corridors between patches at the reef or watershed scale (Gaines et al. 2010), but this may be beyond the capacity of local or regional conservation partners like LCCs, necessitating the formation of complex national or international partnerships.

Finally, human activities affecting conservation often take place at a local level, while planning and management may span ecoregions and decisions are made many hundreds, or even thousands of kilometers from targeted resource areas. Agendas and partnerships must be made at appropriate scales, and practitioners must be prepared to integrate those scales in order to deliver conservation designs across large areas.

Linkage of Terrestrial and Marine Systems

LCD for island settings must integrate terrestrial and aquatic systems, where open system exchange of land, freshwater, and marine features gives rise to complex ecological processes and asymmetrical scales of planning (Stoms et al. 2005; Pressey et al. 2007; Alvarez-Romero et al. 2011). Coral and nearshore fisheries health are tied to complex ridge-to-reef processes that require management of both land and sea (Carpenter et al. 2008; Hughes et al. 2010). Seabird colonies, capable of transferring nutrients and seeds between sea and land, play a large role in plant community structure and ecosystem dynamics on islands, but whether they are increasing native biodiversity or introducing non-native species can vary from setting to setting (Ellis 2005). Migratory land-sea species like seabirds and sea turtles typically require regulatory, rather than spatially delineated, protection measures, making measurable LCD objectives more difficult to track. Integrated land-sea planning must also consider linked processes between realms, because threats may originate in one and affect the other (Alvarez-Romero et al. 2011). In sum, conservation design for the complex processes that underpin the success of island species and ecosystems requires unique methods for assessing and modeling terrestrial, coastal, and marine interfaces (Lagabrielle et al. 2009).

These LCD challenges illustrate not only the ecological disparities between land and sea, but also the different institutional frameworks and actors in each realm. Competing objectives continue to plague conservation practitioners when moving from land to sea and vice versa (TNC 2007; Alvarez-Romero et al. 2011). Marine resource management for an entire archipelago may also operate on a different jurisdictional level than terrestrial conservation efforts on the islands contained within it. Effective LCD for islands must be able to scale both up (to the region) and down (to the local) to meet the conservation priorities within diverse management areas where the links between land and sea transfers may be poorly studied.

Social/Political Capacity

Human factors frequently drive conservation efforts more than ecology or geography, and the broad range of financial, technical, and management capacities can be problematic when attempting to coordinate across multiple islands or areas (Game et al. 2011; Mills et al. 2013). In a typical continental setting, numerous entities (political, environmental, community) may operate within a shared landscape, increasing the potential for collaboration around common resources (Wyborn 2015) as the planning area increases. LCD efforts among some LCCs within the network, including the Conservation Blueprint by the South Atlantic LCC (http://www.southatlanticlcc.org/page/conservation-blueprint) and Peninsular Florida's Conservation Scenarios project (Vargas et al. 2014), provide excellent examples of landscape-level, high-capacity partnership and collaboration. In most island settings, on the other hand, increasing the spatial scale from island to archipelago and beyond may not increase shared capacity, while the complexity of linked terrestrial and marine issues grows as more unique island species and issues are included. Islands with extreme topographic contrasts pose additional challenges to monitoring and modeling efforts, particularly where funding is already limited, and uninhabited islands or atolls can be remote or difficult to manage (McCauley et al. 2013).

LCD also assumes that conservation decision-making processes are shared by all partners, and amenable to common design principles. Because they tend to have large proportions of indigenous human populations, islands within the LCC network are more likely to maintain traditional knowledge systems that are not as readily compatible with the spatially explicit, fixed conservation agenda-setting of LCD. In small island communities, particularly where traditional land tenure systems still hold, it can be undesirable or impossible to apply top-down or static conservation measures to suit LCD (Mills et al.

2013). Even island systems within the same political entity may have diverse cultures and attitudes about conservation. Remoteness, low shared capacity across islands, and cultural values that may not be congruent with Western conservation ideals present significant challenges to the application of traditional LCD in these regions. The island LCD process can unfold quite differently, but broadening the spectrum of social and political capacity that informs and practices conservation design could benefit the LCC network as a whole.

Exposure to Climate Change

Climate change profoundly affects island resources, livelihoods, and biodiversity (Fordham and Brook 2010), and exacerbates the challenges to LCD that we have already described. Changes in moisture and temperature can constrict or expand island species ranges: on large, high islands, for example, warming air temperatures produce upslope range shifts or complete habitat loss for native or endemic species (Raxworthy et al. 2008). This can be compounded by agricultural intensification in mid-elevation habitats as farms migrate to the uplands due to coastal saltwater intrusion (Wong et al. 2005). Abandoned agricultural zones may then become suitable niches for the expansion of invasive species that are already present (Willis et al. 2010; Huang et al. 2011; Ricciardi et al. 2011). Low islands are especially vulnerable to sea-level rise and high waves during extreme storm events, while nearshore, coastal, and higher elevation areas on all islands are impacted by increased sea and air temperatures, drought, and storm runoff (Waycott et al. 2011; Keener et al. 2012). The imminent emergence of novel climates in the tropics (Mora et al. 2013) and the narrower temperature tolerance of tropical species (Deutsch et al. 2008), coupled with the barrier to off-island range shifts, implies that tropical island species are likely to suffer disproportionate losses as climates change. Developing a LCD within such islands is challenged by the threat that many species of conservation concern may not have a viable future habitat in their place of origin.

In the tropics, coral bleaching events as a result of extreme temperatures are well documented (Veron et al. 2009), whereas ocean acidification leads to declines in overall coral formation (Frederiksen et al. 2004). These two global processes, in concert with increased coral disease risk, are projected to eliminate the conditions suitable for complex coral reefs within the next five decades for most reef locations (van Hooidonk et al. 2014; Maynard et al. 2015). In the interim, these complex interactions are dynamic and their relationship with seasonal and cyclic climate variability is poorly understood (Chown et al. 2008) – making target-setting over large, fixed geographic units for LCD difficult due to shifting baseline conditions.

Designing landscape-level conservation under climate change even at the island level is hampered by the paucity of fine-scale climate projections for small islands. Unlike large, contiguous land masses, climate variability and small-scale weather patterns aren’t usually captured in global or even regional climate models for islands (Kingsford et al. 2011). Model downscaling is necessary to reflect the topographic features of islands, as well as complex physical processes that drive local micro-climates, but the downscaling process itself can be both computationally and time-intensive (Timm and Diaz 2009; Wilby et al. 2009; Rummukainen 2010; Zhang et al. 2012). Moreover, downscaled climate information that is available has a high level of uncertainty, and that uncertainty can be difficult to interpret by resource managers who are coordinating across local, regional, or national scales (Wiens and Bachelet 2010).

Nevertheless, island conservation strategies are strongly informed by regional and local climate models. Assessment of natural resource availability, status, and allocation through time and across space may be especially relevant on islands where vulnerability to small climate shifts is high, and species ranges are constricted or unknown (Huang et al. 2011; Price et al. 2012; Vorsino et al. 2014). In larger MPA settings or networks, climate predictions facilitate targeting of areas that are more or less likely to experience disturbances or change (Levy and Ban 2013; van Hooidonk et al. 2015). Ultimately, LCD efforts to focus on describing current and desired future landscape conditions must incorporate uncertainty about global and local climate processes, to avoid static conservation "fixes" that become unsustainable with time. Because many islands and isolated continental settings that are "island-like" are more sensitive to climate-related changes, tools like scenario planning are useful for identifying potential future threats as well as opportunities, in the pursuit of robust policy strategies under uncertainty (Volkery and Ribeiro 2009).

V. Island-Appropriate LCD

In the previous section, we identified five core challenges to implementing LCD in island and island-like settings that make it difficult for some LCCs to meet the biological, physical, and socio-economic metrics that the current reporting framework requires. This section revisits the stages of the LCD process from an island perspective, breaking down the reporting metrics into multiple ecological, spatial, temporal, and jurisdictional levels and exploring different ways to identify priority resources and develop systematic conservation designs that encompass large, diverse, and isolated areas. Examples from the three island LCCs show how they've used LCD to address complex problems, highlighting opportunities for island and continental managers alike to achieve a more dynamic, adaptive design process and product.

In conservation design, biological, spatial, temporal, and socio-political management systems are frequently organized in a hierarchical way, with members and classes that are easily distinguished from one another (Henle et al. 2010). As noted above, scaled processes and dynamics are especially pronounced in islands where endemism is high and species are isolated, dispersal capabilities vary widely among terrestrial and marine species, political and administrative jurisdictions are highly stratified or remote, and climate pressures operate in multiple dimensions at once. Some of the metrics that are relevant for landscape conservation planning and design are listed in Table 1, along with special considerations for island settings that are drawn from the challenges discussed above:

Table 1. LCD metrics and special considerations for island settings as they relate to the 5 key challenges.

LCD Metric	Special Considerations for Islands	Key Challenges
Ecological	• Spacing: multiple conservation areas may be needed to ensure connectivity, or preserve isolation, but may not be available • Buffers: island interfaces, especially terrestrial-marine-freshwater, are in flux, requiring buffers to support monitoring and management of processes of interest, which may not be possible on very small islands • Threats: stressors may be localized or disconnected, and can cause entire habitat or range loss or complex coupled marine-terrestrial use changes • Species: species ranges very small or unknown, surrogates for species or habitat may be required, data limited to higher-order information (i.e. vegetation classes, geology, and landforms)	*Endemism, Connectivity & Scale, Terrestrial-Marine linkages*
Spatial	• Coverage: 100% coverage of LCC geography may be impossible • Planning units: may not be geographically identifiable, must incorporate land-sea processes, variable dispersal rates, units may be regular or irregular • Stratification: extreme topography, spatial heterogeneity may need to be accounted for by layered analyses at different resolutions • Connectivity: suitable areas for supporting processes may or may not be adjacent, movement and transport must be facilitated, isolation and fragmentation may also be the goal • Rates of change: the spatial distribution of climatic conditions is shifting more quickly in islands, reserve systems cannot be static, small regional scales, entire disappearance of available habitat for small-range species	*Connectivity & Scale, Terrestrial-Marine linkages, Exposure to Climate Change, Social/Political Complexity*
Temporal	• Rates of change: climate shifts outpace planning horizons, dynamic approaches to target-setting and management are needed	*Terrestrial-Marine linkages, Exposure to*

	• <u>Uncertainty</u>: scenarios and models of future landscape conditions may not be available	*Climate Change, Social/Political Complexity*
<u>Jurisdictional</u>	• <u>Administration</u>: local administrative units may not fall within larger multi-institutional or international arrangements, political instability, few centralized agencies, traditional land tenure systems • <u>Capacity</u>: high-capacity stakeholders, coordinated management, and broad, regional information may be unavailable • <u>Transferability</u>: LCD may not be adaptable from one island or archipelago in the region to the next, or in neighboring LCCs	*Terrestrial-Marine linkages, Social/Political Complexity*

Identify targets and conduct baseline vulnerability assessments (LCD Phases 1 and 3)

The focus in this stage is to identify priority conservation targets and develop methods for measuring and mapping diversity, and operates primarily in the ecological and spatial dimensions. The LCCs are tasked with assessing existing large-scale conservations efforts, which in island settings may only exist in the marine realm, and identifying the monitoring and information gaps for achieving strategic landscape conservation. Pinpointing priority resources (biological, ecological, or cultural) and conducting baseline vulnerability assessments is the central product for this stage, but the best available science on those resources may be extremely limited or require the use of surrogate species or indicators, while in the spatial dimension planning units may not be geographically identifiable and must incorporate complex land-sea processes and extreme topographies.

Threats are also identified during this stage and may vary in the degree of complexity, structure, or response needed. While threats to landscape integrity like habitat loss, species invasions, illegal activity, or even lack of funding are experienced in continental and insular settings alike, their effects can be exacerbated in islands and archipelagos due to their high endemism and low biodiversity, isolation and small sizes, complex land-sea processes, rapid rates of change due to climate or extreme events, and decentralized or low-capacity institutions.

Set conservation goals (Phases 2, 4, and 6)

An ideal LCD would set goals for priority resources or targeted areas identified in the previous stage, such as a suite of intact, connected, and resilient systems supporting healthy and diverse species. The overall goals of a conservation design should be detailed and preferably quantitative, to facilitate interpretation, operationalization, and evaluation. Threats identified in the previous stage will influence potential management actions for the goals defined in this stage. Continental LCD typically takes the "bigger is better" approach to setting targets for sustainable landscape function, with additional emphasis on system resilience, habitat restoration, ecosystem services, cultural integrity, or species rarity and diversity. But because island settings require more variable objectives to accommodate fragmented or complex habitats, diverse species dispersal distances and rates, and spatial stratification, environmental heterogeneity and dynamic population goals may be more appropriate.

Similarly, the temporal thresholds for continental target setting are often unrealistic in islands, where rates of climate change outpace planning and management time horizons. Even annual successional stages are compounded by islands' unique vulnerability to extreme events or prolonged periods of drought. The LCD framework calls for high-level plans to move the landscape from current to desired future conditions, which while already a challenge in continental settings may be impossible in islands. Indeed, the focus may be on preventing further degradation and maintaining current priority resource conditions. Therefore, dynamic approaches to target-setting in rapidly shifting landscapes must integrate different levels of terrestrial/marine vulnerability, and changing rates and patterns of biodiversity. Goal-setting, rather than being fixed from the outset, is an iterative stage that must be reassessed throughout the LCD process, to ensure that goals continue to directly correspond to the outputs specified in the final design.

Conservation design (Phase 5)

The conservation design product is a portfolio of priority areas, methodologies, and management actions to address the goals, and in traditional continental settings it should have broad generalizability or transferability within the LCC and its neighboring regions – this is less relevant for island LCD. A methodological approach may be as simple as GIS layer stacking or empirical optimization of conservation targets, for example, or it may involve complex computational models. Management actions can range from simple infrastructure upgrades to local observer networks, reserve designation, legislation, and strategic partnerships. The most important aspect of this stage of the LCD process is to ensure that methodologies and management strategies match the ecological priorities and goals defined in the previous stages, and that they are adaptable to the shifting spatial, temporal, and ecological characteristics of the landscape in question.

One of the greatest challenges for island managers is the uncertainty inherent in all stages of landscape conservation design. Regional downscaling of climate models over small land areas with extreme topography introduces orders of magnitude greater uncertainty than over larger continental management areas. This can be further complicated when attempting to model and manage for rare, small range species. Decisions about how to link ecological priorities with design goals, or monitor, implement, and manage insular landscapes in the face of shifting baselines must be made with explicit acknowledgement of uncertainty to avoid wasting already limited human and financial resources.

Adaptive management and outputs (Phase 7)

The final stage of LCD is perhaps the most important one, as the LCC generates practical tools that facilitate adaptation strategies and alternate management approaches for meeting the conservation goals defined in previous stages. Ongoing monitoring and evaluation criteria assess LCD effectiveness, while decision support tools and information delivery ensure that regional stakeholders and partners have what they need to make decisions based on the best science available.

The socio-political complexity of island settings requires a diverse approach to information delivery and evaluation. Administrative units at the local level may not fall within the boundaries of larger institutional or international arrangements, and high personnel turnover or low financial capital threatens continuity of longer-term adaptive management strategies. Traditional land tenure systems and marine use rights may not facilitate a conservation design that operates from the top down, requiring greater investment in and iterations of priorities, as well as the identification of local champions for design goals. In many insular regions, these challenges mean that priority conservation actions may need to occur at different times within the defined geographic region, and the generation and dissemination of interim products become critical to meeting LCD reporting goals as well as reaching target audiences across broad and disconnected areas. Finally, an LCD for one part of an insular region may not be transferrable to another island or archipelago, or a neighboring LCC, which can present a considerable challenge to LCC efforts to consolidate conservation management plans and spatial products over their entire geography.

With this in mind, we highlight different approaches that the three island LCCs are taking to achieve LCD, identifying gaps or areas of disagreement among the components of their LCD products, and finding ways forward for meeting the five core challenges at the landscape level.

Example 1: Aleutian and Bering Sea Islands (ABSI)

The ABSI LCC is comprised of low lying, sparsely populated, and isolated islands within a marine area between Alaska and Russia of nearly 40,000 km^2. The entire region has a population of about 7,000 people living in nine communities. This includes eight Alaska Native tribes who continue to practice subsistence fishing and hunting in some of the most remote island communities in the US. Approximately 50% of the seafood is produced in the U.S. comes from fisheries in this region. Millions of seabirds and many iconic marine mammals like walrus and polar bear depend on the region for habitat, which is threatened by landscape-level stressors such as sea-level rise, increasing ocean temperatures and acidification, altered storm patterns, and globally and locally source pollutants and contaminants (Poe and Burn 2013). Commercial marine vessel traffic poses risks to ABSI resources and habitat through ship strikes and groundings, invasive species introductions, and potential contaminant spills. In 2012 the LCC and partners began using Automated Identification System (AIS) data to track commercial vessels traveling in and around the highly connected marine environments of the Aleutian archipelago, with the goal of identifying vulnerable species and regions, particularly as transpolar routes will become more accessible with reduced Arctic sea ice (https://absilcc.org/science/sitepages/shipping.aspx). Table 2 lists some of the metrics and design components associated with this project, and evaluates its effectiveness at meeting the needs for LCD accordingly.

Table 2. ABSI LCC marine vessel tracking LCD.

LCD Metrics	**Satisfies LCD Reporting Needs?**
Ecological: Ecoregion	No – does not yet encompass all priority resources
Spatial: Region	Yes – covers 100% of LCC geography
Temporal: Season	No – future shipping patterns, climate variability and change will impact LCD goals at much longer timescales, although future scenario analysis is underway
Jurisdictional: State	Yes – partners at all levels
Design Components	
Threats: Marine pollution, invasive species, direct ship contact	Yes – threats are easily identified and evaluated throughout the process
Methods: AIS tracking	Yes – geospatial data products form backbone of project and adaptation strategies No – lack of climate variability and change projections for long-term planning
Management: Buffers, efficiency, preparedness	Yes – diverse options for linking to other LCD efforts in the region No – shifting baselines due to long-term changes not addressed
Goals: Ecological integrity, ecosystem services, rarity of species	Yes – directly supports landscape-scale decision-making, indirectly informs protection of rare, threatened, or endemic species

The vessel traffic vulnerability assessment resulting from this work will allow ABSI to revisit and refine conservation objectives and design according to partner goals. One immediate result has been a vessel routing measure that was recently approved by the International Maritime Organization to avoid a 50 mile buffer around five regions identified by this project. In a state where fishing is the third largest industry (Leask et al. 2001), connecting regional economic interests with landscape-level stressors makes this project environmentally, politically, and economically relevant to a variety of stakeholders within the LCC's geography. It also creates a space for localized investigations of highly vulnerable marine and seabird habitats, as well as coastal community outreach on incident preparedness. The project is easily linked to other LCD efforts by ABSI to address the risks associated with the impacts of invasive species. Those results will be integrated with two additional vulnerability assessments, one focused on climate change and the other on contaminants and pollutants. The hope is that by examining the collection of these four stressors, design elements can be generated to mitigate compounding and interacting threats to key resources and services in the region. However, the integration of these four stressors highlights mismatches between the temporal seasonal scale and more long-term goals that will be strongly impacted by annual or decadal climate change and variability. The vulnerability of some islands, particularly those at high latitudes, to shifting climate baselines and even the opening of the Arctic to new shipping routes and development as sea ice disappears have not yet been incorporated in this LCD.

Example 2: Pacific Islands Climate Change Cooperative (PICCC)

Second only in size to the Arctic LCC with over 2 million square kilometers of ocean and 2,000 islands of varying geologic origin spread across the Pacific Ocean, the PICCC is responsible for some of the most vulnerable land and seascapes, as well as human populations, in the network. As one of the dominant features of the tropical Pacific, coral reefs form complex habitats for thousands of species that provide food, livelihoods, and coastal protection (Bryant et al. 1998; Cesar 2000). Reefs in the US-affiliated Pacific Islands range from large barrier formations to smaller fringing or patch reefs, often adjacent to, and utilized by, indigenous communities. To assess the vulnerability that coral reefs, and their dependent organisms, communities, and livelihoods will face under a changing climate, the PICCC used global climate projections for four Representative Concentration Pathway (RCP) emissions scenarios to show how and when the twin stresses of rising ocean temperatures and ocean acidification may eliminate coral reefs around the world (van Hooidonk et al. 2014, 2015). The assessment indicates the decade in which these global stressors will reach critical levels that are incompatible with coral reef function in a given location, and a web-based visualization tool makes the projections available to the public (http://coralreefwatch.noaa.gov/climate/projections/piccc_oa_and_bleaching/index.php).

Table 3. PICCC coral reef vulnerability LCD.

LCD Metrics	**Satisfies LCD Reporting Needs?**
Ecological: Community	No – Pacific-wide resolution not well-suited for individual reef community action, does not encompass all priority resources
Spatial: Continent	Yes – covers 100% of LCC geography
Temporal: Decadal	Yes – climate outlook appropriate for long-term resource management No – ignores extreme events, climate variability
Jurisdictional: International	Yes – facilitates large-scale legislation No – limited use for local-scale decision making
Design Components	
Threats: Ocean acidification, ocean warming	Yes – global stressors clearly identified No – does not incorporate regional or local stressors like pollution, exploitation, physical destruction
Methods: Climate modeling, vulnerability mapping, visualization tool	Yes – simple, use-inspired products provide straightforward and regional information using the best available data
Management: Protected area	Yes – outputs suitable for large-scale MPA planning
Goals: Ecological integrity, ecosystem resilience	No – outputs (grid cells) do not match the targets (reef communities)

When evaluated from the perspective of island-appropriate LCD (Table 3) this project clearly articulates a landscape-level threat to conservation priorities in the LCC region, and derives a useful tool for managers to utilize when making decisions about coral reef protection; indeed, President Obama's recent expansion of the Pacific Remote Islands Marine National Monument was informed by this assessment, and other Pacific nations are now considering new MPA locations. The ability to compare results across emissions scenarios also captures uncertainty inherent in the global climate models and shows a variety of responses at particular thresholds. However, the climate model resolution is very coarse, and each 1° x 1° grid cell can contain multiple and diverse reef structures, in addition to multi-island or even international stakeholders, which limits its utility for local resource managers. The global models also cannot resolve patterns of thermal stress and acidification that result from short-term or seasonal processes, or extreme events that could strongly influence the predicted effects. This lack of temporal and spatial resolution limits the application of these results to the scale at which management of reefs and watersheds occurs. Nevertheless, while this reveals the mismatch between priority targets (coral communities) and outputs (model grid cells), it highlights the opportunity for the PICCC to use this project as a springboard for identifying regional partners for building reef resilience in a changing climate.

Example 3: Caribbean (CLCC)

The CLCC, at present is largely focused on domestic conservation within the US Caribbean (i.e. Puerto Rico and the US Virgin Islands), but is establishing international collaborations under the recognition that priority resources (e.g. sea birds, coral reefs, fish assemblages, etc.) cannot be effectively managed within US boundaries alone. The magnitude of global stressors such as sea level rise, warmer temperatures, changing precipitation patterns, ocean acidification, stronger storms, marine debris, and land-based sources of pollution all require regional (and by definition international in the Caribbean) efforts and coordination. On top of the threats, the resources themselves seldom adhere to political boundaries; seabirds and sea turtles, for example, maintain home ranges extending even beyond the Caribbean and require international coordination.

One of the highest priority resources the CLCC has identified are the cays systems (including the coral and seagrass communities surrounding them). Cays are simply small islands that surround the main islands. There are over 750 cays in the US Caribbean alone and they support a wide variety of endemic lizards, birds, and plants, they are critical nesting and roosting habitat for numerous seabirds, provide stop-over habitat for neotropical migrant song birds and shorebirds, and many have significant cultural value. All cay-systems (the cays and the surrounding marine habitats) are profoundly susceptible to sea-level rise, ocean acidification, stronger storms and changing weather patterns. Conservation partners recognized that while many cays have their own management plans, none of the plans are integrated and management responsibilities for the cays fall under several different entities (including different federal agencies, commonwealth and territorial agencies, and even some private ownership). There is serious concern that the services the cays provide and the species they support could erode over time due to the lack of coordinated management and a shared long-term vision. There is, however, a shared recognition that the cays could be more effectively managed as an integrated network than as individual units.

The CLCC Cays Conservation Action Team (CAT) was established, bringing together stakeholders representing over 14 organizations having a role in cay management, to derive that shared vision through LCD. Together the partners of the Cay CAT are identifying objectives, priority resources, indicators, and strategies to achieve their shared vision of the future condition and functioning of the network of cays in the US Caribbean and beyond. By developing a LCD for the network of cays, rather than as individual units, priority resources can be more effectively managed by partners. A single island is insufficient to support a population of seabirds, but within a network of islands the CAT can now ask, for each of its priorities, how many cays are needed to support a robust metapopulation resilient to climate change and other anthropomorphic stressors, where should those cays be or what's the best spatial arrangement of cays to support the priority resources, and what restoration practices and where are they needed? These and related questions can be asked and balanced across all the priorities even when the spatial extent and capacity for "multiple uses" of cays is limited, therefore trade-offs only become apparent when all the resources and their management needs can be overlaid on the network of cays.

Table 4. CLCC endemic iguana LCD.

Metrics	**Satisfies LCD Reporting Needs?**
<u>Ecological</u>: Species	Yes – multiple species serving as surrogate species also targets multiple specific habitat types
<u>Spatial</u>: Region	Yes – entire LCC geography is involved, and projects scale down to unique island-specific issues
<u>Temporal</u>: Yearly, decadal	Yes – forward-looking climate and sea-level rise projections combined with shorter-term planning horizons Yes – captured and addressed through ongoing planning iterations

Jurisdictional: International	Yes – government, academic, NGO, and private sector partnerships avoid pitfalls of top-down mandates, sensitive to political/cultural differences Yes – captured and addressed through ongoing planning iterations
Design Components	
Threats: Land use change, illegal harvesting, funding	Yes – threats range from local to regional, and correspond to the best available data
Methods: Species distribution modeling, climate model downscaling, scenario planning, partnerships	Yes – multiple models and data sources provide tailored sectoral information and useful interim products
Management: Species translocations, invasive species eradications, cross-jurisdiction education	Yes – robust suite of management options, tailored to the needs of each sub-region
Goals: Ecological integrity, maintenance of threatened and endangered species, and protection of cultural resources	Yes – outputs are directly tied to targets, with added-value interim products for other uses

In this LCD, the CAT and the CLCC steering committee serve as the basis for fostering the domestic and international partnerships necessary to develop a shared vision of the future conservation landscape. The priority targets are species and other (e.g. cultural) resources deemed effective as surrogates for the at-risk habitat types (mangroves, beaches, coral reefs and seagrass beds, and dry tropical forests), and achieve habitat and ecosystem-level conservation goals across the region (Table 4). Although some species are well distributed and known, others are rare and highly dispersed, so monitoring and modeling processes are tailored to the information available. Seen from this perspective, this collaborative and unique conservation effort provides an example of a suite of monitoring, data and information sharing, and restoration projects that constitute regional island LCD across jurisdictional boundaries. This analysis is also sensitive to the diversity of desired uses and cultural and ethical values that communities hold toward the region's cays. Political differences between international entities could impede region-wide conservation efforts, and there is clearly a need for additional funding and human resources to achieve successful implementation. Long project horizons risk shifting environmental or social conditions, making iterative reevaluation of the threats and goals essential to the success of the LCD.

VI. Discussion and Opportunities

These examples from island regions within the LCC network illustrate the diversity of approaches that need to be taken to meet the developing framework for landscape conservation design. We've shown that LCD approaches that focus on contiguous landscapes and geographically identifiable planning units present inherent problems to managers in oceanic archipelagos, as island chains lack terrestrial connectivity but have high marine connectivity, and conservation actions typically take place within small units or at the island-level. Individual islands themselves may be fragmented, with terrestrial and marine complexity that is poorly understood or difficult to model. A centralized political management infrastructure and conservation partnerships often are not established in low-capacity island regions, or their interests may not align with those of local communities or groups. Managers on resource-poor islands struggle with limited data availability and high levels of uncertainty in the sources that do exist. Some island systems belong to larger government enterprises that don't actively fund conservation or research, and significant travel costs or weak infrastructure further complicate coordinated management efforts. Lastly, the interactions between changing climate conditions on islands and other challenges such as increased global trade, resource exploitation, and species invasions are poorly understood, and rapidly shifting baselines can render spatially-fixed conservation designs moot.

The approaches to regional conservation design described in this paper allow managers to broaden the view of the landscape in terms of scope and scale in order to design, and more importantly deliver, island conservation in a strategic and collaborative fashion. There are many ways to approach conservation planning in a spatially explicit way at island or archipelago-appropriate scales, but a clear understanding of the objectives, socio-political constraints and actions, and trade-offs is needed (Alvarez-Romero et al. 2011; Halpern et al. 2013). When coupled with the numeric self-scoring methods required by each LCC, a dynamic adaptive management approach can help account for each component within the LCD measurement requirements and facilitate easy linkages across projects throughout the region.

The three island LCCs have used the LCD efforts described in this paper as a springboard for continued regional engagement and new initiatives throughout their geographies. The broad cooperation among various stakeholders embodied by the Aleutian Islands Risk Assessment, released in fall 2014, is one model that ABSI LCC hopes to leverage to address other land and sea stressors. One natural outgrowth that could receive similar broad interest and support would be the characterization of how environmental and climate conditions could complicate or exacerbate the known risks associated with marine vessel traffic. This approach allows ABSI to use momentum gained from addressing the “easier” vessel traffic issue and attempt to direct that toward the more complex issues of climate change in the region. The PICCC has used the decadal projections of coral reef impacts to frame an upcoming adaptation initiative on the ability of island social-ecological systems to buffer the projected impacts of change in marine resources. And the CLCC is using LCD to help coordinate multiple agencies across many political jurisdictions to develop a shared vision for cay conservation and to bring more resources to bear in the Caribbean. The LCD is a central building block toward establishing successful international partnerships and generating a variety of conservation strategies toward the development of a broader Caribbean conservation design.

More importantly, examples from the island LCCs here have demonstrated best practices for confronting the five core challenges that islands – as well as many continental settings – tend to face when designing conservation efforts at the landscape scale. Based on these experiences, we highlight the following strengths and opportunities for operationalizing LCD within the LCC network and beyond:

Create designs that are inclusive of multiple species, habitats, or ecosystems
While some conservation designs are developed to be species-specific, it’s more likely that collective action could be taken to benefit conservation of species groups, communities, or ecosystems that focus on minimizing or preventing the introduction of invasive species and controlling other human impacts, such as development. While these may require new or modified conservation tactics and monitoring schemes, both the ABSI and the CLCC have chosen LCD approaches that encompass multiple species and islands to achieve a suite of stakeholder-defined goals, including supporting protected area networks, improving trade and transportation policies, increasing habitat restoration efforts, and addressing invasive species to minimize risk.

A forward-looking approach that encompasses multiple islands and large spatial scales can also help accommodate species that can no longer persist in their original range, due to large-scale stressors like climate change. Equally valid in this context is the consideration of metapopulations of species that have very limited ranges, such as salamander conservation design taking shape in the southeastern states, and planning for shifting species distributions over time, as partners within the CLCC are doing for coqui frog conservation in Puerto Rico and ground lizards in the US Virgin Islands.

Embrace the local, and engage partners farther up the chain
Conservation decisions in remote island systems are strongly driven by local stakeholders, often removed from broader regional and international networks. Finding common ground among the interests of land

owners, resource managers, residents, and conservation practitioners is an important facet of LCD in the island settings reviewed here, particularly where there is reduced total capacity. In turn, developing shared priorities and strategies within a comprehensive conservation design helps avoid wasted resources, redundancy, and one-off projects that don't correspond to the long view required for managing rapidly changing island landscapes. By choosing thematic or focal areas of work with diverse stakeholders, the LCC is able to generate a more integrated long-term science strategy and conservation design that links drivers of the system across scales to particular landscapes, habitat features, and species.

To promote sustainable landscapes through conservation design, finding new – even seemingly unlikely – conservation partners like industry can aid in the prevention of habitat losses, damage, or species invasions. In the Aleutians, for example, marine invasive species foul equipment and facilities used by commercial fisheries and the maritime industry, while the spread of those species can further threaten transportation waterways and traditional fishing areas. Particularly in regions where funding and personnel resources for conservation entities may be limited, innovative projects that are inclusive of higher-capacity stakeholders like industry and also complement their economic or political interests has the potential for farther reaching success. A system of coordinated actions by government, communities, tribes, and industry to minimize species loss or promote healthy ecosystems fits squarely within the LCD framework. Such efforts may even have less uncertainty when compared with designed systems of landscape level corridors and refugia that are based on unknown future socioeconomic conditions and climate states (the latter of which is very much the case for Alaska's LCCs).

Gaps and uncertainties can be products, too

While missing data sources and uncertain model projections can pose challenges to landscape-level conservation, LCD provides partners with a way to formalize the need for information and coordinate or share the best available resources. Lower-capacity regions have to be especially creative in identifying surrogate species or habitats for measuring conservation success, for example, or communicating and mitigating uncertainties about future climate shifts. Examples from the island LCCs have shown that approaches to conservation that incorporate unconventional indicators or measurement strategies can fit within the LCD framework, providing the LCCs and beyond with innovative ways to coordinate and evaluate their efforts. Scenario-based designs in particular allow for simultaneous consideration of multiple possible futures and the exploration of their consequences, which can be especially useful in long-range planning for compounding uncertainties under climate change. Even products that inform conservation practices at an international scale – the PICCC coral reef vulnerability project, for example – can be built upon at a more localized and targeted level.

Traditional sources of environmental knowledge can also fit the LCD framework, because they are generally highly spatial in nature. LCC stakeholders include strong indigenous groups that have developed a rich body of environmental knowledge. Places and processes of ancestral importance are being captured in designs implemented by LCCs throughout the network, and used to fill gaps in historical climate records, for example, or land use scenario building across highly variable geographies through time. Prioritizing natural and cultural resources with all available stakeholders from the outset of an LCD increases the amount of information available for decision making, in addition to leveraging new opportunities with local partners in conservation science.

Add a regulatory or thematic component to terrestrial-marine linkages

Matching spatial scales between land and sea interfaces is a clear challenge that island conservation practitioners face. Connecting commercial fisheries interests with coastal management or development projects requires diverse action teams whose individual priorities are comprehensively articulated under a broader regulatory framework. The "ridge-to-reef" management approach to watershed conservation in the Hawaiian islands is one example of this, but continental LCCs have also prioritized land-to-sea connections in conservation design. The Eastern Tallgrass and Prairie LCC is focused on reducing sediment transport from Midwestern agricultural zones to the Gulf of Mexico, while the Upper Midwest and Great Lakes LCC has engaged stakeholders across multiple economic sectors to develop policies that protect priority species in the Great Lakes region in the face of projected climate change.

Because of the difficulties of identifying a suite of landscape-characteristics that favor most species in a complex region that spans land and sea, LCD can also be conceived of as issue-based, rather than geography-based, identifying large-scale processes or key interactions and representing the management priorities in a thematic, rather than geographic, way. A process-based approach still allows for the identification of priority areas and targets within the LCC for conservation efforts and also more readily allows for scaling projects up or down to link across watersheds, islands, ecoregions, or partnership geographies.

Incorporate variable objectives into dynamic designs

High institutional turnover, limited capacity, and shifting project funds or timelines are challenges that impact many conservation designs, but especially those in isolated island settings. A dynamic and adaptable approach to LCD can provide the LCCs with a way to directly tie the outputs of individual landscape conservation programs to management goals, even as conditions change over time. Priority setting and LCD should be iterative processes that acknowledges and anticipates those changes, by continuously incorporating the results and lessons learned from stakeholder input, research, modeling, and monitoring efforts.

Approaches to LCD that attempt to mitigate threats to priority resources in terms of best practices that resonate across and “work for” a wide variety of stakeholders benefit significantly from this iterative reevaluation. Preventing the introduction of invasive species, for example, requires regular assessment of the threats to identify new pathways – and new partners. As project timelines outlast staffing or funding resources, the LCC should also develop institutional memory with interim products that are useable both as benchmark tools for reporting as well as springboards for future collaborations and conservation efforts.

VII. Conclusion

The LCD framework for the Fish and Wildlife Service remains under development, and the challenges to meet changing standards and priorities differ across the LCC network. We hope that this paper has highlighted some of the particular challenges that islands face when designing conservation plans at the landscape level, and by experimenting with different ways to meet those challenges has also broadened the interpretation of what LCD is in both form and function. A clear understanding of the diverse and critical features of habitats, communities, and ecosystems within the landscape should drive the structure of conservation design – and this encompasses the breadth of both island and continental settings.

Each LCC in the network is a forum and a catalyst for landscape-level conservation efforts, bringing together technical experts to protect shared resources. They are tasked with building diverse coalitions around complex conservation issues like invasive species, pollution, climate change impacts, and more, and LCD is both the learning process of those partnerships and the living product of their coordinated efforts. Rather than a rigid set of steps and phases, LCD can present opportunities for new ways to engage partners, leverage resources, and achieve conservation objectives: the island LCCs discussed here, with their unique features, have underscored that fact. Bridging the realities of island conservation design to the prevailing interpretation of LCD highlights opportunities for mutual assistance, facilitates the exchange of information on threats and management techniques, and stimulates common initiatives in neighboring geographies. Moreover, the challenges that islands – and other regions – face can become strengths and opportunities for advancing conservation science and finding creative solutions to traditional design problems.

Many of the ecological, socioeconomic, institutional, and methodological challenges specific to islands and other similar settings can only be addressed by sharing experiences across groups and regions, making an effective reporting tool essential for the function of the network as a whole. While the LCD framework for the network continues to be developed, we believe that these lessons from dynamic conservation design in islands give practitioners a menu of different options for achieving an adaptive suite of products that are consistent with the existing LCD metrics, helping to create a flexible and powerful design tool for the wide variety of settings in which the LCCs must succeed.

VIII. References

Allen, G. R. 2008. Conservation hotspots of biodiversity and endemism for Indo-Pacific coral reef fishes. *Aquatic Conservation-Marine and Freshwater Ecosystems* 18 (5):541-556.

Almany, G. R., M. L. Berumen, S. R. Thorrold, S. Planes, and G. P. Jones. 2007. Local replenishment of coral reef fish populations in a marine reserve. *Science* 316 (5825):742-744.

Alvarez-Romero, J. G., R. L. Pressey, N. C. Ban, K. Vance-Borland, C. Willer, C. J. Klein, and S. D. Gaines. 2011. Integrated land-sea conservation planning: the missing links. *Annual Review of Ecology, Evolution, and Systematics* 42:381-409.

Blackburn, T. M., P. Cassey, R. P. Duncan, K. L. Evans, and K. J. Gaston. 2004. Avian extinction and mammalian introductions on oceanic islands. *Science* 305 (5692):1955-1958.

Bryant, D., L. Burke, J. McManus, and M. Spalding. 1998. *Reefs at risk: a map-based indicator of threats to the world's coral reefs*. Washington, DC: World Resources Institute.

Buckley, L. B., and W. Jetz. 2007. Insularity and the determinants of lizard population density. *Ecology Letters* 10 (6):481-489.

Campellone, R., A. Bartuszevige, T. Chouinard, J. Lujan, T. Miewald, B. Murry, R. Nelson, K. O’Hara, A. Poe, and A. Robertson. 2014. *Minimum standards for conservation design at landscape-scales (Landscape Conservation Design). Recommendations from the Landscape Conservation Design Minimum Standards Working Group to the US Fish and Wildlife Service*. Washington, DC: US Fish and Wildlife Service Office of Science Applications.

Carpenter, K. E., M. Abrar, G. Aeby, R. B. Aronson, S. Banks, A. Bruckner, A. Chiriboga, J. Cortes, J. C. Delbeek, L. DeVantier, G. J. Edgar, A. J. Edwards, D. Fenner, H. M. Guzman, B. W. Hoeksema, G. Hodgson, O. Johan, W. Y. Licuanan, S. R. Livingstone, E. R. Lovell, J. A. Moore, D. O. Obura, D. Ochavillo, B. A. Polidoro, W. F. Precht, M. C. Quibilan, C. Reboton, Z. T. Richards, A. D. Rogers, J. Sanciangco, A. Sheppard, C. Sheppard, J. Smith, S. Stuart, E. Turak, J. E. N. Veron, C. Wallace, E. Weil, and E. Wood. 2008. One-third of reef-building corals face elevated extinction risk from climate change and local impacts. *Science* 321 (5888):560-563.

Cesar, H. 2000. Coral reefs: their functions, threats, and economic value. In *Collected essays on the economics of coral reefs,* ed. H. Cesar, 14-39. Kalmar, Sweden: CORDIO, Department for Biology and Environmental Sciences, Kalmar University.

Chapin III, F., G. Kofinas, and C. Folke. 2010. *Principles of ecosystem stewardship: resilience-based natural resource management in a changing world*. New York, NY: Springer.

Chapin III, F., S. Trainor, P. Cochran, H. Huntington, C. Markon, M. McCammon, A. McGuire, and M. Serreze. 2014. Ch. 22: Alaska. In *Climate change impacts in the United States: The Third National Climate Assessment*, eds. J. Melillo, T. Richmond and G. Yohe, 514-536. Washington, DC: US Global Change Research Program.

Chown, S. L., J. E. Lee, and J. D. Shaw. 2008. Conservation of Southern Ocean islands: invertebrates as exemplars. *Journal of Insect Conservation* 12 (3-4):277-291.

Clavero, M., and E. García-Berthou. 2005. Invasive species are a leading cause of animal extinctions. *Trends in Ecology & Evolution* 20 (3):110-110.

Cook, J. A., N. G. Dawson, and S. O. MacDonald. 2006. Conservation of highly fragmented systems: the north temperate Alexander Archipelago. *Biological Conservation* 133 (1):1-15.

Courchamp, F., J. L. Chapuis, and M. Pascal. 2003. Mammal invaders on islands: impact, control and control impact. *Biological Reviews* 78 (3):347-383.

Cuaron, A. D., M. A. Martinez-Morales, K. W. McFadden, D. Valenzuela, and M. E. Gompper. 2004. The status of dwarf carnivores on Cozumel Island, Mexico. *Biodiversity and Conservation* 13 (2):317-331.

Deutsch, C. A., J. J. Tewksbury, R. B. Huey, K. S. Sheldon, C. K. Ghalambor, D. C. Haak, and P. R. Martin. 2008. Impacts of climate warming on terrestrial ectotherms across latitude. *Proceedings of the National Academy of Sciences of the United States of America* 105 (18):6668-6672.

Duncan, R. P., A. G. Boyer, and T. M. Blackburn. 2013. Magnitude and variation of prehistoric bird extinctions in the Pacific. *Proceedings of the National Academy of Sciences of the United States of America* 110 (16):6436-6441.

Ehler, C., and F. Douvere. 2009. *Marine spatial planning: a step-by-step approach toward ecosystem-based management*. Paris, France: Intergovernmental Oceanographic Commission and Man and the Biosphere Programme.

Ellis, J. C. 2005. Marine birds on land: a review of plant biomass, species richness, and community composition in seabird colonies. *Plant Ecology* 181 (2):227-241.

Feeley, K. J., and M. R. Silman. 2011. The data void in modeling current and future distributions of tropical species. *Global Change Biology* 17 (1):626-630.

Fordham, D. A., and B. W. Brook. 2010. Why tropical island endemics are acutely susceptible to global change. *Biodiversity and Conservation* 19 (2):329-342.

Frederiksen, M., M. P. Harris, F. Daunt, P. Rothery, and S. Wanless. 2004. Scale-dependent climate signals drive breeding phenology of three seabird species. *Global Change Biology* 10 (7):1214-1221.

Gaines, S. D., C. White, M. H. Carr, and S. R. Palumbi. 2010. Designing marine reserve networks for both conservation and fisheries management. *Proceedings of the National Academy of Sciences of the United States of America* 107 (43):18286-18293.

Game, E. T., G. Lipsett-Moore, R. Hamilton, N. Peterson, J. Kereseka, W. Atu, M. Watts, and H. P. Possingham. 2011. Informed opportunism for conservation planning in the Solomon Islands. *Conservation Letters* 4 (1):38-46.

Gilbert-Norton, L., R. Wilson, J. R. Stevens, and K. H. Beard. 2010. A meta-analytic review of corridor effectiveness. *Conservation Biology* 24 (3):660-668.

Gillespie, R. G. 1999. Naiveté and novel perturbations: conservation of native spiders on an oceanic island system. *Journal of Insect Conservation* 3 (4):263-272.

Gillespie, R. G., and G. K. Roderick. 2002. Arthropods on islands: colonization, speciation, and conservation. *Annual Review of Entomology* 47:595-632.

Halpern, B. S., C. J. Klein, C. J. Brown, M. Beger, H. S. Grantham, S. Mangubhai, M. Ruckelshaus, V. J. Tulloch, M. Watts, C. White, and H. P. Possingham. 2013. Achieving the triple bottom line in the face of inherent trade-offs among social equity, economic return, and conservation. *Proceedings of the National Academy of Sciences of the United States of America* 110 (15):6229-6234.

Halpern, B. S., and R. R. Warner. 2003. Matching marine reserve design to reserve objectives. *Proceedings of the Royal Society B-Biological Sciences* 270 (1527):1871-1878.

Harter, D. E. V., S. D. H. Irl, B. Seo, M. J. Steinbauer, R. Gillespie, K. A. Triantis, J.-M. Fernandez-Palacios, and C. Beierkuhnlein. 2015. Impacts of global climate change on the floras of oceanic islands - projections, implications and current knowledge. *Perspectives in Plant Ecology* Evolution and Systematics 17 (2):160-183.

Henle, K., W. Kunin, O. Schweiger, D. S. Schmeller, V. Grobelnik, Y. Matsinos, J. Pantis, L. Penev, S. G. Potts, I. Ring, J. Simila, J. Tzanopoulos, S. van den Hove, M. Baguette, J. Clobert, L. Excoffier, E. Framstad, M. Grodzinska-Jurczak, S. Lengyel, P. Marty, A. Moilanen, E. Porcher, D. Storch, I. Steffan-Dewenter, M. T. Sykes, M. Zobel, and J. Settele. 2010. Securing the conservation of biodiversity across administrative levels and spatial, temporal, and ecological

scales: research needs and approaches of the SCALES project. *Gaia-Ecological Perspectives for Science and Society* 19 (3):187-193.
Huang, D. C., R. A. Haack, and R. Z. Zhang. 2011. Does global warming increase establishment rates of invasive alien species? A centurial time series analysis. *PLoS One* 6 (9). doi: 10.1371/journal.pone.0024733.
Hughes, T. P., N. A. J. Graham, J. B. C. Jackson, P. J. Mumby, and R. S. Steneck. 2010. Rising to the challenge of sustaining coral reef resilience. Trends in Ecology & Evolution 25 (11):633-642.
Hulme, P. E. 2009. Trade, transport and trouble: managing invasive species pathways in an era of globalization. *Journal of Applied Ecology* 46 (1):10-18.
Kaluza, P., A. Kolzsch, M. T. Gastner, and B. Blasius. 2010. The complex network of global cargo ship movements. *Journal of the Royal Society Interface* 7 (48):1093-1103.
Keener, V., J. Marra, M. Finucane, D. Spooner, and M. Smith. 2012. Climate change and Pacific islands: indicators and impacts. Report for *The 2012 Pacific Islands Regional Climate Assessment*. Washington, DC: Island Press.
Kier, G., H. Kreft, T. M. Lee, W. Jetz, P. L. Ibisch, C. Nowicki, J. Mutke, and W. Barthlott. 2009. A global assessment of endemism and species richness across island and mainland regions. *Proceedings of the National Academy of Sciences of the United States of America* 106 (23):9322-9327.
Kingsford, R. T., and J. E. M. Watson. 2011. Climate change in Oceania - a synthesis of biodiversity impacts and adaptations. *Pacific Conservation Biology* 17 (3, Sp. Iss. SI):270-284.
Lagabrielle, E., M. Rouget, K. Payet, N. Wistebaar, L. Durieux, S. Baret, A. Lombard, and D. Strasberg. 2009. Identifying and mapping biodiversity processes for conservation planning in islands: a case study in Reunion Island (Western Indian Ocean). *Biological Conservation* 142 (7):1523-1535.
Leask, L., M. Killorin, and S. Martin. 2001. *Trends in Alaska's people and economy*. Anchorage, AK: Institute of Social and Economic Research, University of Alaska Anchorage.
Levy, J. S., and N. C. Ban. 2013. A method for incorporating climate change modelling into marine conservation planning: an Indo-west Pacific example. *Marine Policy* 38:16-24.
Lodge, D. M., S. Williams, H. J. MacIsaac, K. R. Hayes, B. Leung, S. Reichard, R. N. Mack, P. B. Moyle, M. Smith, D. A. Andow, J. T. Carlton, and A. McMichael. 2006. Biological invasions: recommendations for US policy and management. *Ecological Applications* 16 (6):2035-2054.
MacArthur, R. H., and E. O. Wilson. 1967. *The theory of island biogeography*. Princeton, NJ: Princeton University Press.
Maynard, J., R. van Hooidonk, C. M. Eakin, M. Puotinen, M. Garren, G. Williams, S. F. Heron, J. Lamb, E. Weil, B. Willis, and C. D. Harvell. 2015. Projections of climate conditions that increase coral disease susceptibility and pathogen abundance and virulence. *Nature Climate Change* 5 (7):688-694.
McCauley, D. J., E. A. Power, D. W. Bird, A. McInturff, R. B. Dunbar, W. H. Durham, F. Micheli, and H. S. Young. 2013. Conservation at the edges of the world. *Biological Conservation* 165:139-145.
Meyer, C. G., Y. P. Papastamatiou, and K. N. Holland. 2007. Seasonal, diel, and tidal movements of green jobfish (Aprion virescens, Lutjanidae) at remote Hawaiian atolls: implications for marine protected area design. *Marine Biology* 151 (6):2133-2143.
Mills, M., R. L. Pressey, N. C. Ban, S. Foale, S. Aswani, and A. T. Knight. 2013. Understanding characteristics that define the feasibility of conservation actions in a common pool marine resource governance system. *Conservation Letters* 6 (6):418-429.
Mora, C., A. G. Frazier, R. J. Longman, R. S. Dacks, M. M. Walton, E. J. Tong, J. J. Sanchez, L. R. Kaiser, Y. O. Stender, J. M. Anderson, C. M. Ambrosino, I. Fernandez-Silva, L. M. Giuseffi, and T. W. Giambelluca. 2013. The projected timing of climate departure from recent variability. *Nature* 502 (7470):183-187.
Myers, N., R. A. Mittermeier, C. G. Mittermeier, G. A. B. da Fonseca, and J. Kent. 2000. Biodiversity hotspots for conservation priorities. *Nature* 403 (6772):853-858.

Nassauer, J. I., and P. Opdam. 2008. Design in science: extending the landscape ecology paradigm. *Landscape Ecology* 23 (6):633-644.
National Fish, Wildlife and Plants Climate Adaptation Partnership (NFWPCAP). 2012. *National Fish, Wildlife and Plants Climate Adaptation Strategy*. Washington, DC: Association of Fish and Wildlife Agencies, Council on Environmental Quality, Great Lakes Indian Fish and Wildlife Commission, National Oceanic and Atmospheric Administration, and US Fish and Wildlife Service.
O'Dowd, D. J., P. T. Green, and P. S. Lake. 2003. Invasional 'meltdown' on an oceanic island. *Ecology Letters* 6 (9):812-817.
Planes, S., G. P. Jones, and S. R. Thorrold. 2009. Larval dispersal connects fish populations in a network of marine protected areas. *Proceedings of the National Academy of Sciences of the United States of America* 106 (14):5693-5697.
Poe, A. J. and D. Burn. 2013. *Addressing environmental stressors in the Aleutian Islands and Bering Sea: a strategic science plan*. Anchorage, AK: Aleutian and Bering Sea Island Landscape Conservation Cooperative, US Fish and Wildlife Service.
Poirine, B., and A. Moyrand. 2001. Insularity and governance: the case of French Polynesia. *Public Organizational Review: A Global Journal* 1:193-213.
Pressey, R. L., M. Cabeza, M. E. Watts, R. M. Cowling, and K. A. Wilson. 2007. Conservation planning in a changing world. *Trends in Ecology & Evolution* 22 (11):583-592.
Price, J. P., J. D. Jacobi, S. M. Gon III, D. Matsuwaki, L. Mehrhoff, W. Wagner, M. Lucas, and B. Rowe. 2012. *Mapping plant species ranges in the Hawaiian Islands - developing a methodology and associated GIS layers*. Reston, VA: US Geological Survey.
Raxworthy, C. J., R. G. Pearson, N. Rabibisoa, A. M. Rakotondrazafy, J.-B. Ramanamanjato, A. P. Raselimanana, S. Wu, R. A. Nussbaum, and D. A. Stone. 2008. Extinction vulnerability of tropical montane endemism from warming and upslope displacement: a preliminary appraisal for the highest massif in Madagascar. *Global Change Biology* 14 (8):1703-1720.
Ricciardi, A., L. A. Jones, A. M. Kestrup, and J. M. Ward. 2011. Expanding the propagule pressure concept to understand the impact of biological invasions. In *Fifty years of invasion ecology: the legacy of Charles Elton*, ed. D. M. Richardson, 225-235. West Sussex, UK: Wiley-Blackwell.
Rodda, G. H., and J. A. Savidge. 2007. Biology and impacts of Pacific island invasive species. 2. Boiga irregulatis, the brown tree snake (Reptilia : Colubiridae). *Pacific Science* 61 (3):307-324.
Ruiz, G., and J. T. Carlton. 2003. *Invasive species: vectors and management strategies*. Washington, DC: Island Press.
Rummukainen, M. 2010. State-of-the-art with regional climate models. *Wiley Interdisciplinary Reviews-Climate Change* 1 (1):82-96.
Russell, J. C., B. M. Beaven, J. W. B. MacKay, D. R. Towns, and M. N. Clout. 2008. Testing island biosecurity systems for invasive rats. *Wildlife Research* 35 (3):215-221.
Sax, D. F., and S. D. Gaines. 2008. Species invasions and extinction: the future of native biodiversity on islands. *Proceedings of the National Academy of Sciences of the United States of America* 105:11490-11497.
Simberloff, D. 2000a. Extinction-proneness of island species - causes and management implications. *Raffles Bulletin of Zoology* 48 (1):1-9.
———. 2000b. No reserve is an island: marine reserves and nonindigenous species. *Bulletin of Marine Science* 66 (3):567-580.
Simberloff, D. 2011. How common are invasion-induced ecosystem impacts? *Biological Invasions* 13 (5):1255-1268.
Smith Jr., W. J., J. Mount, D. Bennett, and P. Shed. 2014. Collaborative research methodologies and the construction of a national geospatial clearinghouse to conserve biodiversity in the Federated States of Micronesia. *Applied Geography* 54:198-208.
Stoms, D. M., F. W. Davis, S. J. Andelman, M. H. Carr, S. D. Gaines, B. S. Halpern, R. Hoenicke, S. G. Leibowitz, A. Leydecker, E. M. P. Madin, H. Tallis, and R. R. Warner. 2005. Integrated coastal

reserve planning: making the land-sea connection. *Frontiers in Ecology and the Environment 3* (8):429-436.

The Nature Conservancy (TNC). 2007. *Advancing ecosystem-based management - a decision support toolkit for marine managers. Florida northwest coast: conserving wetlands and mitigating hazards: meeting joint objectives (case study).* Seattle, WA: The Nature Conservancy Global Marine Initiative.

Timm, O., and H. F. Diaz. 2009. Synoptic-statistical approach to regional downscaling of IPCC twenty-first-century climate projections: seasonal rainfall over the Hawaiian Islands. *Journal of Climate* 22 (16):4261-4280.

US Fish and Wildlife Service (USFWS). 2008. *Strategic Habitat Conservation handbook: a guide to implementing the technical elements of Strategic Habitat Conservation*. Washington, DC: US Fish and Wildlife Service.

van Hooidonk, R., J. A. Maynard, D. Manzello, and S. Planes. 2014. Opposite latitudinal gradients in projected ocean acidification and bleaching impacts on coral reefs. *Global Change Biology* 20 (1):103-112.

van Hooidonk, R., J. A. Maynard, L. Liu, and S. N.-K. Lee. 2015. Downscaled projections of Caribbean coral bleaching that can inform conservation planning. *Global Change Biology* 21 (9):3389-3401.

Vargas, J., C. Flaxman, and B. Fradkin. 2014. *Landscape conservation and climate change scenarios for the state of Florida: a decision support system for strategic conservation. Summary for decision makers*. San Francisco, CA: Geodesign Technologies Inc.

Veitch, C., and M. Clout. 2002. Turning the tide: the eradication of invasive species. Proceedings of the International Conference on Eradication of Island Invasives, held at the University of Auckland, 19 to 23 February 2001. *Occasional Papers of the IUCN Species Survival Commission* 27:i-viii, 1-414.

Veron, J. E. N., O. Hoegh-Guldberg, T. M. Lenton, J. M. Lough, D. O. Obura, P. Pearce-Kelly, C. R. C. Sheppard, M. Spalding, M. G. Stafford-Smith, and A. D. Rogers. 2009. The coral reef crisis: the critical importance of < 350 ppm CO2. *Marine Pollution Bulletin* 58 (10):1428-1436.

Vitousek, P. M., C. M. Dantonio, L. L. Loope, M. Rejmanek, and R. Westbrooks. 1997. Introduced species: a significant component of human-caused global change. *New Zealand Journal of Ecology* 21 (1):1-16.

Volkery, A., and T. Ribeiro. 2009. Scenario planning in public policy: understanding use, impacts and the role of institutional context factors. *Technological Forecasting and Social Change* 76 (9):1198-1207.

Vorsino, A. E., L. B. Fortini, F. A. Amidon, S. E. Miller, J. D. Jacobi, J. P. Price, S. O. Gon, and G. A. Koob. 2014. Modeling Hawaiian ecosystem degradation due to invasive plants under current and future climates. *PLoS One* 9 (5). doi: 10.1371/journal.pone.0095427.

Waycott, M., L. McKenzie, J. Mellors, J. Ellison, M. Sheaves, C. Collier, A.-M. Schwarz, A. Webb, J. Johnson, and C. Payri. 2011. Vulnerability of mangroves, seagrasses, and intertidal flats in the tropical Pacific to climate change. In *Vulerability of tropical Pacific fisheries and aquaculture to climate change,* eds. J. Bell, J. Johnson and A. Hobday, 297-368. Noumea, New Caledonia: Secretariat of the Pacific Community.

Whittaker, R., and J.-M. Fernandez-Palacios. 2007. *Island biogeography: ecology, evolution, and conservation*. Oxford, UK: Oxford University Press.

Wiens, J. A., and D. Bachelet. 2010. Matching the multiple scales of conservation with the multiple scales of climate change. *Conservation Biology* 24 (1):51-62.

Wilby, R. L., J. Troni, Y. Biot, L. Tedd, B. C. Hewitson, D. M. Smith, and R. T. Sutton. 2009. A review of climate risk information for adaptation and development planning. *International Journal of Climatology* 29 (9):1193-1215.

Willis, C. G., B. R. Ruhfel, R. B. Primack, A. J. Miller-Rushing, J. B. Losos, and C. C. Davis. 2010. Favorable climate change response explains non-native species' success in Thoreau's woods. *PLoS One* 5 (1). doi: 10.1371/journal.pone.0008878.

Wong, P., E. Marone, P. Lana, M. Fortes, D. Moro, J. Agard, and L. Vicente. 2005. Chapter 23: island systems. In *Millennium Ecosystem Assessment*, 663-680. Washington, DC: Island Press.
Wyborn, C. 2015. Cross-scale linkages in connectivity conservation: adaptive governance challenges in spatially distributed networks. *Environmental Policy and Governance* 25 (1):1-15.
Zavaleta, E. S., R. J. Hobbs, and H. A. Mooney. 2001. Viewing invasive species removal in a whole-ecosystem context. *Trends in Ecology & Evolution* 16 (8):454-459.
Zhang, C., Y. Wang, A. Lauer, and K. Hamilton. 2012. Configuration and evaluation of the WRF model for the study of Hawaiian regional climate. *Monthly Weather Review* 140 (10):3259-3277.